Int J Ophthalmol, Vol. 9, No. 2, Feb.18, 2016 www. ijo. cn
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·Clinical Research·

Ocular biomechanical measurements on post-keratoplasty corneas using a Scheimpflug-based noncontact device

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Received: 2014-08-23 Accepted: 2015-02-03

Abstract

• AIM: To analyse ocular biomechanical properties, central corneal thickness (CCT) and intraocular pressure (IOP) in post-keratoplasty eyes, as compared to normal subjects, with a new Scheimpflug-based technology. Moreover, biomechanical data were correlated with the size and age of the donor and recipient corneas.

• METHODS: Measurements were conducted on 46 eyes of 46 healthy patients without any corneal pathology (age: 53.83 ±20.8y) and 30 eyes of 28 patients after penetrating keratoplasty (age: 49.43 ±21.34y). Ten biomechanical parameters, the CCT and IOP were recorded by corneal visualization Scheimpflug technology (CorVis ST) using high-speed Scheimpflug imaging. Keratometry values were also recorded using Pentacam HR system. Scheimpflug measurements were performed after 43.41± 40.17mo (range: 11-128mo) after the keratoplasty and after 7.64±2.34mo (range: 5-14mo) of suture removal.

• RESULTS: Regarding the device-specific biomechanical parameters, the highest concavity time and radius values showed a significant decrease between these two groups (P=0.01 and P<0.001). None of other biomechanical parameters disclosed a significant difference. The CCT showed a significant difference between post-keratoplasty eyes as compared to normal subjects (P=0.003) using the CorVis ST device. The IOP was within the normal range in both groups (P=0.84). There were no significant relationships between the keratometric data, the size of the donor and recipient, age of the donor and recipient and biomechanical properties obtained by CorVis ST.

• CONCLUSION: The ocular biomechanics remain stable after penetrating keratoplasty according to the CorVis ST measurements. Only two from the ten device-specific parameters have importance in the follow-up period after penetrating keratoplasty.

• **KEYWORDS:** corneal visualization Scheimpflug technology; ocular biomechanics; penetrating keratoplasty
DOI:10.18240/ijo.2016.02.09

Modis L Jr., Hassan Z, Szalai E, Flaskó Z, Berta A, Nemeth G. Ocular biomechanical measurements on post-keratoplasty corneas using a Scheimpflug-based noncontact device. *Int J Ophthalmol* 2016;9(2):235-238

INTRODUCTION

The currently used diagnostic techniques are capable of measuring only the static parameters of the anterior segment, however, the cornea also has viscoelastic properties[1]. Up until recently, the only device used for conducting the *in vivo* measurement of ocular biomechanical properties has been the Ocular Response Analyzer (ORA, Reichert Ophthalmic Instruments, Depew, New York, USA) which became commercially available in 2005[2-3].

With the introduction of ORA, an emphasis has been placed on the biomechanical measurements of the cornea in the diagnosis of keratoconus and glaucoma, and on the assessment of the outcomes of refractive surgeries and corneal collagen cross-linking therapies[4-7].

The initial publications have reported differences in the parameters measured with ORA in healthy and keratoconus eyes and in those subsequent to refractive surgeries[8-9].

Recently, a new device, corneal visualization Scheimpflug technology (CorVis ST, Oculus Inc., Wetzlar, Germany), has been introduced using a high intensity air impulse for biomechanical measurements and applying an ultra-high-speed Scheimpflug camera. The equipment has the potential to measure the amplitude of maximal applanation and the time taken to reach this applanation. CorVis ST also monitors the corneal velocity between the first and second applanation and the distance of the two apexes at highest concavity in time. In addition, the images of the Scheimpflug camera, capturing 4330 frames/s, are also recorded on a video throughout an examination period of 30ms.

Our aim was to investigate the device-specific biomechanical parameters of eyes after penetrating keratoplasty (PK) as compared to normal subjects with CorVis ST and to assess possible correlations between postoperative keratometric data, size of the donor and recipient, age of the donor and recipient cornea and biomechanical properties using a Scheimpflug-based noncontact device.

SUBJECTS AND METHODS

Our patient was informed about the measurements and written informed consent was obtained from all of our subjects. The research protocol of this retrospective study adhered to the tenets of the Declaration of Helsinki.

Subjects Measurements were conducted in 46 eyes of 46 healthy patients without any corneal pathology or anterior segment disease (age: 53.83 ±20.8y) and 30 eyes of 28 patients after penetrating keratoplasty (age: 49.43 ±21.34y). The male/female ratio was 20/26 in the normal group and 14/14 in the post-keratoplasty group. The preoperative diagnoses included keratoconus (n=10), corneal dystrophy (n=10), pseudophakic bullous keratopathy (n=5), corneal leucoma (n=3), keratoglobus (n=1) and rekeratoplasty after herpetic keratitis (n=1). CorVis ST measurements were performed after 43.41±40.17mo (range: 11-128mo) after the keratoplasty and 7.64±2.34mo (range: 5-14mo) after suture removal. In addition, keratometry values were recorded by Pentacam HR imaging system. The size of the donor and recipient and age of the donor and recipient corneas were taken from medical and eye bank records.

Penetrating Keratoplasty Technique The conventional Moria trephination system (Anthony, France) was used to trephine the donor and recipient corneas in each case. Corneal buttons (age of donor: 58.00 ±11.24y) between 6.5-7.5 mm in diameter were fixed with 16 bites 10/0 nylon running sutures. Local corticosteroid therapy (Maxidex, Alcon Laboratories, Forth Worth, Texas, USA) was continued for six month in all patients. All the corneas were clear and transparent at the time of evaluation, without the presence of inflammation or neovascularisation.

Measurements The measurements were carried out using the CorVis ST device, software version 1.00r24 rev. 772. CorVis ST is a non-contact tonometer and pachymeter measuring ten specific ocular biomechanical parameters as well. This device uses an ultra-high-speed Scheimpflug camera (4330 frames/s) with a light source of a blue LED light at a wavelength of 455 nm. The air impulse employs a metered, symmetrical and fixed maximal internal pump pressure of 25 kPa.

Due to the air impulse, the cornea goes through three distinct phases: first applanation, highest concavity (HC) and second applanation. During these phases, a number of specific parameters are recorded: the maximum deformation amplitude (HC of the cornea), the time taken to reach it, the first and second applanation times, the length of the flattened cornea, the maximum corneal velocity at the first and second applanations, the peak distance, which is the distance of the two apexes at HC, and a radius value which represents the radius of the curvature of a circle that fits with the central concave curvature at the HC. The central corneal thickness (CCT) and intraocular pressure (IOP) were also determined by the device.

The patient is in sitting position with his or her chin on the chinrest and their forehead against the equipment. The examiner targets the centre of the cornea with a joystick, enabling the patients to see a red fixating light. The adjusting direction needed to centre on the corneal apex is seen on the display. With an accurate setting, the air puff automatically starts, after which the data are exported to a computer.

Statistical analysis was performed with the MedCalc 10.0 software. Descriptive statistical results were described as mean and standard deviation (SD). Independent-samples t-test was used for comparing the data of the two groups. Multiple regression analyses were performed with the ten specific CorVis ST data in combination as independent variables and keratometric data, the size of the donor and recipient, and age of the donor and recipient as dependent variable. A P value below 0.05 was considered to be statistically significant.

RESULTS

The specific parameters measured with the CorVis ST are shown in detail in Table 1. Regarding the device-specific biomechanical parameters, only the highest concavity time and radius value disclosed a significant decrease between the two groups (P=0.01 and P<0.001). None of the other biomechanical parameters showed a significant difference.

Multiple regression analyses showed that there were no significant relationship between horizontal radius of curvature of the cornea, vertical radius of curvature of the cornea, size of the donor, size of the recipient, age of the donor, age of the recipient and CorVis ST specific parameters (r=0.68, P=0.22; r=0.64, P=0.36; r=0.61, P=0.49; r=0.61, P=0.51; r=0.54, P=0.46; r=0.51, P=0.73, respectively).

After surgery, pachymetry showed significantly thicker corneas in the PK group as compared to normal eyes measured with CorVis ST (P=0.003). The IOP was within the normal range in both groups (P=0.84).

DISCUSSION

Recently, a novel piece of equipment has been introduced for measuring ocular biomechanical properties *in vivo*. CorVis ST measures ten specific biomechanical parameters and in addition CCT, IOP using an air impulse. Our aim was to assess these new biomechanical data following PK as compared to a normal group. Moreover, the present study correlated the obtained biomechanical parameters with keratometry readings and the size and age of the donor and recipient corneas.

Table 1 Corneal biomechanical measurements obtained with the CorVis ST

Parameters	Subjects[1]		P^2
	Normal	Postkeratoplasty	
Applanation 1			
Time (ms)	7.24±0.22 (7.17-7.30)	7.25±0.47 (7.08-7.42)	0.86
Length (mm)	1.79±0.25 (1.72-1.87)	1.81±0.23 (1.72-1.89)	0.79
Velocity (m/s)	0.15±0.03 (0.15-0.16)	0.14±0.03 (0.13-0.15)	0.08
Applanation 2			
Time (ms)	21.58±0.40 (21.45-21.7)	21.52±0.50 (21.34-21.70)	0.61
Length (mm)	1.90±0.46 (1.76-2.04)	1.92±0.50 (1.73-2.11)	0.86
Velocity (m/s)	-0.36±0.06 (-0.38- -0.34)	-0.37±0.10 (-0.40- -0.33)	0.74
Highest concavity			
Time (ms)	16.89±0.49 (16.74-17.03)	16.48±0.77 (16.19-16.76)	0.01
Peak distance (mm)	3.23±1.10 (2.91-3.56)	3.64±1.22 (3.18-4.10)	0.14
Radius (mm)	7.55±0.72 (7.34-7.77)	6.42±0.89 (6.09-6.75)	<0.001
Def. ampl. max. (mm)	1.08±0.09 (1.06-1.11)	1.14±0.18 (1.07-1.20)	0.12
IOP (mm Hg)	14.66±1.90 (14.10-15.23)	14.50±4.39 (12.86-16.14)	0.84
Pachymetry (μm)	545.57±31.97 (536.07-555.06)	585.2±58.25 (561.15-609.25)	0.003

Def. ampl. max.: Maximal deformation amplitude; IOP: Intraocular pressure. [1]Mean±standard deviation (95% confidence interval); [2]Independent-samples *t*-test.

In biomechanical measurements, the cornea is considered to be a viscoelastic substance [1]. Up until recently, the only equipment applied in the measurement of ocular biomechanical properties was the ORA. Biomechanical measurements are applied in the diagnosis of keratoconus[8-10], but the two main parameters showed low sensitivity and specificity in distinguishing between normal and keratoconus groups [10-11]. Yenerel *et al* [12] found correlations between the severity of keratoconus and the viscoelastic properties of the cornea.

Investigating the biomechanics has a role in the effect of studies of refractive surgeries[4], corneal collagen crosslinking (CXL) [6-7], and also in glaucoma diagnosis [5]. CXL causes significant biomechanical differences, but only when applying the latest parameters of the ORA software[7].

The measurement and evaluation of IOP after PK is a challenging task because of the irregularities of the donor surface [13-14]. There are only a few papers analysing biomechanical properties after PK with ORA[12,15-21], and most of these studies conclude that the corneal biomechanics weaken after PK [18,20], whereas deep anterior lamellar keratoplasty (DALK) did not affect these values[18]. Hosny *et al* [18] concluded that corneas after PK have weaker biomechanical properties than normal corneas, whereas DALK preserves the biomechanical strength of the corneas due to the intact Descemet's membrane. In contrast, Jafarinasab *et al* [17] stated that no significant difference can be measured between PK and DALK in terms of IOP and biomechanical properties. Improved corneal biomechanics were observed after PK compared to keratoconus eyes, yet they did not reach a normal level [12]. Yenerel *et al* [12] found significantly lower corneal hysteresis (CH) and corneal resistance factor (CRF) values in keratoconus and post-keratoplasty eyes when compared to normal eyes. Hosny *et al* [18] found the same, with decreased biomechanical data after PK. Shin *et al* [16] found that CH decreased but CRF increased after PK, however this was without any significant difference.

The biomechanical data were lower after one year of PK, and the difference in the biomechanical properties measured with ORA was statistically significant between normal and post-keratoplasty eyes[20]. They could not observe differences according to the preoperative diagnosis [20] or the follow-up period [17]. John *et al* [19] found lower ORA data after descemetorhexis and endokeratoplasty compared to the normal group.

We found that the HC time and radius values of CorVis ST showed a significant decrease between post-keratoplasty and normal eyes. According to our hypothesis, these two parameters are sensitive enough to show difference between these two patient groups. None of the other 8 device-specific parameters showed significant differences between the two groups. We think that there can be two possible explanations behind these results. First, there are really no significant differences in these new biomechanical parameters (obtained by CorVis ST) between the two groups. Second, it is possible that this device or its measured parameters are not sensitive enough to differentiate between these two groups. In a recent paper of Maeda *et al*[21], the deformation amplitude, measured with CorVis ST, in PK eyes was significantly higher than those of the control eyes. Maybe this is explainable by different population sample and different population ages.

Another reason for the difference can be the follow-up time after keratoplasty (a mean of 43.41mo in our study) or presence of sutures (in our study: only after suture removal). The mean CCT was higher after PK measured by ORA [20]. We found the same alteration using the CorVis ST. In addition, the present study showed no correlations between specific CorVis ST parameters and radii of curvature of the cornea, size of the donor, size of the recipient, age of the donor or age of the recipient after perforating keratoplasty.

According to our data with a new device measuring ocular biomechanics, only the time of HC, the radius value and the CCT showed differences in the PK group as compared to the normal group. There was no statistical difference regarding all other specific parameters of CorVis ST. In this study, the eyes after suture removal were the inclusion criteria. There was no difference in the IOP or biomechanics between postkeratoplasty eyes with or without sutures according to a previous paper that used ORA [15]. We did not find any problem with keratoplasty wounds after CorVis ST measurements and so, similar to the study of Jafarinasab *et al* [17], we also propose that biomechanical measurements with high-intensity air-puff are safe after PK.

In conclusion, the ocular biomechanics are stable after PK according to the Corvis ST measurements. The highest concavity time and radius value of CorVis ST can be important in follow-up studies after PK. The role of the other device-specific parameters of CorVis ST in PK needs further clarification and investigation.

ACKNOWLEDGEMENTS

Conflicts of Interest: Modis L Jr., None; **Hassan Z,** None; **Szalai E,** None; **Flaskó Z,** None; **Berta A,** None; **Nemeth G,** None.

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